In-Flight Radiometric Calibration Plans for the Earth Observing System-Multi-angle Imaging SpectroRadiometer

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Abstract -- The Multi-angle Imaging SpectroRadiometer (MISR) will fly on the EOS-AM1 spacecraft, and provide global data sets with nine discrete view directions per scene. The instrument's radiometric scale is achieved by use of detector standards. On-orbit, photodiodes measure reflected light from solar-illuminated deployable Spectralon panels. The cameras simultaneously view the panels, providing the needed calibration data inputs. Other calibration methodologies include vicarious calibration and histogram equalization. Coefficients, as derived from the various methods, are weighted to produce a single determination of the gain and offset parameters. This process is repeated at monthly intervals to insure the calibration is maintained. Routine product generation makes use of these calibration coefficients, and also corrects for instrument-dependent errors in the radiance determination. These latter processing steps include corrections for camera out-of-band response, focal-plane scattering, and detector-to-detector non-uniformity of response. This paper reviews the MISR standard radiometric product and the in-flight radiometric calibration and characterization plans.

EXPERIMENT OVERVIEW

The Multi-angle Imaging Spectro-Radiometer (MISR) instrument is part of an Earth Observing System (EOS) payload to be launched in 1998. The purpose of MISR is to study the ecology and climate of the Earth through the acquisition of systematic, global multi-angle imagery in reflected sunlight. MISR will monitor top-of-atmosphere and surface reflectances on a global basis, and will characterize the shortwave radiative properties of aerosols, clouds, and surface scenes.

The MISR instrument consists of nine pushbroom cameras. It takes about 7 minutes of flight time to observe any given region at all nine view angles. The cameras are arranged with one camera pointing toward the nadir (designated An), one bank of four cameras pointing in the forward direction (designated Af, Bf, Cf, and Df in order of increasing off-nadir angle), and one bank of four cameras pointing in the aftward direction (designated Aa, Ba, Ca, and Da). Images are acquired with nominal view angles, relative to the surface reference ellipsoid, of 0°, ±26.1°, ±45.6°, ±60.0°, and ±70.5°. Each camera uses four Charge-Coupled Device (CCD) line arrays in a single focal plane. The line arrays consist of 1504 photoactive pixels. Each line array is filtered to provide one of four MISR spectral bands. The spectral band shapes are nominally gaussian, with bandcenters at 443, 555, 670, and 865 nm. MISR will acquire images in each of its channels with spatial sampling ranging from 275 m (250 m cross-track in the nadir) to 1.1 km (1.0 km cross-track in the nadir), depending on the on-board pixel averaging mode used prior to transmission of the data.

Each of MISR's photoactive pixel elements, when stimulated with incident radiation, responds with proportional output measured in digital counts. This response is measured during calibration, and reported as the best-fit gain and offset parameters. Gain is primarily a function of the optics transmittance (having a strong field-angle dependence), the filter transmittance, CCD quantum efficiency, the amplification of the electronics and the analog-to-digital conversion factor. Slight local deviations in response are due to filter pinholes or spatter sites, as well as CCD site defects. Pixel response may change with time, due to contaminant polymerization and radiation-induced effects to the lens and electronics. Because degradation is anticipated, the radiometric response is monitored routinely during the mission. The quantization and utilization of this response in MISR radiometric product generation is the primary objective of the MISR in-flight radiometric calibration program. Fig. 1 summarizes the program, as will be discussed in this paper.

Specifications require MISR to maintain absolute radiometric accuracy to within 3% (1σ confidence), for a 100% diffusely reflective scene, throughout the mission life. For a 5% scene, the requirement is to maintain 6% accuracy. Pixel-to-pixel relative calibration requirements are ±0.5% and ±1%, respectively, for these two scenes. Specifications also exist for nonuniform scenes, polarization sensitivity, and out-of-band rejection [1].

RADIOMETRIC PRODUCT GENERATION

During standard product generation, MISR will do a series of processing steps termed radiance scaling and

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radiance conditioning. These make use of the sensor radiometric calibration and scene-specific data, respectively. Specifically, radiometric conditioning performs pixel-to-pixel nonuniformity of response corrections, point-spread-function (PSF) deconvolution, and spectral corrections. *Radiance scaling* and *radiance conditioning* are MISR unique terms, but refer to the usage of otherwise conventional processing methodologies.

Radiance Scaling

The inverse process to calibration is the determination of incident radiance for a given camera DN value. This process is termed radiance scaling.

For MISR, the best-fit to the radiometric (DN vs. L) transfer curve has been obtained by using a second-order polynomial:

$$G_2L^2 + G_1L + DN_o = DN - DN_v \ . \qquad (1)$$

where

- L is the sensor incident radiance [W m^{-2} sr^{-2} μm^{-1}],
- DN is the digital number,
- G_2, G_1, and DN_o are best fit parameters to the sensor radiative transfer curve, and
- DN_v is the video offset voltage, unique for each line of data, and measured by the overclock pixels for that line.

It is noted that prior to data transmission, the MISR system electronics square-root encode the output of the analog-to-digital converters. Some loss in resolution at the upper end of the dynamic range curve is sacrificed in favor of a reduced data rate. The DN values in (1) have had this square-root encoding reversed. Thus, the presence of a quadratic term in (1) is unrelated to this feature.

Preflight calibration has determined that, for the MISR cameras, the CCD response is nearly linear, and the second order coefficient is quite small. Inclusion of this term improves the radiance retrieval at the lowest end of the detector transfer curve.

Radiance Conditioning

Pixel non-uniformity correction ... is the process of adjusting for instrument on-board pixel-averaging. As many as four adjacent pixels may be averaged by the instrument prior to data transmission. The exact number will depend upon the selected camera configuration used during data acquisition. The process of pixel averaging introduces a radiometric error in the data, depending on the magnitude of the gain deviation among the pixels averaged, and the inhomogeneity of the scene. This error exists because the hardware design does not incorporate any adjustment for individual pixel response differences before the data are averaged.

Deviations in response across any four MISR pixels is typically 3%. Under these conditions the radiometric error would be less than 0.5% for extreme scene inhomogeneities, and no corrections are necessary. However, for each array there are a dozen or so pixels which violate this uniformity requirement.

The algorithm used in this correction first estimates the relative scene radiance incident on each pixel. MISR will be continually operated with the red channel of each camera supplying unaveraged data. The relative scene homogenity is assumed to be spectrally independent in this algorithm. With this information, and the pixel response coefficients, a radiance adjustment can be made.

PSF deconvolution ... is a process that allows the radiance product to maintain accuracy in the presence of high contrast scenes. During Engineering Model testing several unexpected focal plane scattering phenomena were characterized [2]. At that time it was determined that scattering from filter spatter sites was the cause of larger than anticipated out-of-band response. Additionally, reflections between the CCD and filter were observed. For the latter, a low-level scatter as far away as 30 pixels from the geometric image point was observed. In convolving this PSF with a "lake" scene, radiometric errors of 17% were predicted. The lake was 24x24 pixels in size, 5% in reflectance, and surrounded by a land background of 50% reflectance. The radiometry was compared using the center 8x8 pixels of the convolved and original targets. By using a maximum likelihood algorithm, a simple kernel of 1x6 pixels in dimension was used to restore the original target. This was done within a half-dozen iterations, producing a scene meeting the 2% radiometric error specification.

Spectral corrections ... are used to compute the band-weighted radiance that a nominal filter passband would have measured, while viewing a given scene. The correction is in two steps. First, the out-of-band response is subtracted using the preflight spectral calibration data. The MISR band data is used to approximate the scene spectral shape in this algorithm. Secondly, a passband of nominal center wavelength and bandwidth is assumed. The radiance retrieved from this idealized response function is computed. This correction allows MISR Level 2 (Science Products) to proceed without consideration of the individual spectral response functions for each of the 1504 detectors x 9 camera pixel elements.

Level 1B1 Radiance Product

The above processing steps are used to produce the MISR radiance product, termed the Level 1B1 Radiometric

Product. Processing occurs at the Distributed Active Archive Center (DAAC), and is done on every transmitted image. Image co-registration and geolocation occurs at the next level of processing and produces the Level 1B2 Georectified Radiance Product.

Ancillary Radiometric Product

The coefficients used in radiometric product generation are delivered to the DAAC in the form of the Ancillary Radiometric Product (ARP). Also included in the ARP is radiance uncertainty, spectral and instantaneous field-of-view (IFOV) information. The ARP is generated at the MISR Science Computing Facility (SCF). It is updated at monthly intervals, or as needed to maintain the calibration of the sensor.

IN-FLIGHT CALIBRATION

The Level 1B1 algorithm development, ARP generation, and product validation is the responsibility of the in-flight radiometric calibration and characterization (IFRCC) team, which resides at NASA/ Jet Propulsion Laboratory (JPL). The SCF processing facilities will be used to provide these deliverables, as well as routine characterization products and reports.

The in-flight calibration of MISR is provided by combining coefficients determined from multiple methodologies. A weighting scheme will facilitate this process. Uncertainty analyses for each method, frequency of data supplied for a given technique, and data quality indicators will be used in the weighting scheme. The methodologies involve the use of the On-Board Calibrator (OBC) hardware, an independent vicarious determination, and response prediction based on trending analysis and scene studies. Spatially and spectrally featureless targets are used to establish the calibration response.

On-Board Calibrator

The OBC consists of a wavelength set of High-Quantum Efficiency (HQE) trapped photodiodes, and five wavelength sets of radiation resistant PIN (p-i-n intrinsic layers) photodiodes. One PIN set is positioned on a goniometer, which scans through the along-track camera view angles. These detector standards are used to measure the radiance reflected from one of two Spectralon calibration panels.

Monthly, MISR will be commanded into Calibration Mode. During this time the instrument will collect data over oceans on the dark side of the orbit. These data will monitor dark current spatial variability. Then, over each pole, in turn, the Spectralon panels will be deployed to calibrate the aftward-viewing and nadir or forward-viewing and nadir cameras. These polar observations will collect light through a varying atmospheric path through the earth's limb to the Sun. Atmospheric attenuation will allow calibration of the MISR detectors through a range of illumination conditions. The detector standards will be used to measure the radiance as it changes with time.

Vicarious Calibration

Vicarious calibration techniques can utilize data from 1) high altitude sensor underflights, 2) surface radiance observations, or 3) surface reflectance observations. The preferred approach, Method 1, will utilize a MISR simulator (AirMISR) which will fly on the ER-2 aircraft. At 20 km altitude, AirMISR will need little atmospheric corrections to produce a measure of the top-of-atmosphere radiances. Method 2 utilizes a hemispherical scanning radiometer, PARABOLA III, to measure surface-reflected radiances and downwelling diffuse radiances. These are propagated from surface to top-of-atmosphere using a characterization of the atmospheric state and a radiative transfer code. Method 3 has the disadvantages of requiring a two-path radiance propagation (Sun-to-surface and surface to sensor), and therefore is the least desirable. It is, however, the simplest to implement, as PARABOLA data are referenced to a reflectance standard, and no radiometer calibration is required.

Relative Adjustments

Following OBC and vicarious coefficient weighting, the derived coefficients are next plotted in time against the other monthly determinations. A trend analysis on these data is done, and the smoothed parameters computed at the current point in time. This is done in order to avoid abrupt changes in the calibration coefficients. This trend analysis is believed to be more representative of the sensor response, which is known to be highly stable on short time scales, and otherwise expected to degrade slowly with time. In addition, histogram equalization is used [3], as necessary, to refine the pixel-to-pixel relative response values. Here, Earth-scene data are used to produce a histogram of measured radiance levels. Using a large number of observations, each pixel response is adjusted until the amplitude of the histogram is the same for each pixel. This is adjustment is made by using a sliding window approach, correcting pixel responses from first one spatial zone, then another. This step process allows pixels to be compared which have the same viewing geometry, avoiding differences in atmospheric path and surface bidirectional reflectance.

IN-FLIGHT CHARACTERIZATION

Other IFRCC responsibilities include the characterization of the sensor during flight. Characterization is the measurement of the typical behavior of instrument properties which may affect the accuracy or quality of its response or derived data products. The in-flight characterization includes the determination of the radiometric errors for specific scene types, such as high contrast scenes, and a variety of scene spectral signature types. Noise analysis will include the determination of signal-to-noise ratio versus radiance input, and a check for the presence of coherent noise (that of a fixed frequency pattern). Spectral stability will be investigated, to the extent possible. Filter life-test studies, and correlation with Moderate Resolution Imaging Spectroradiometer (MODIS) filter stability determinations, are the best data sources.

CALIBRATION INTEGRITY

Calibration integrity is the process of validating and certifying the Level 1B1 product. Traceability of MISR data products is accomplished with the detector standards. These are used through the preflight, OBC, and vicarious determinations of the sensor calibration. Radiometric verification will be provided by cross-comparisons with MODIS and Système Probatoire d'Observation de la Terre (SPOT) sensors, as well as with the routine analysis of MISR imagery over desert sites.

The IFRCC team will also be responsible for the development of quality assessment indicators for the Level 1B1 data.

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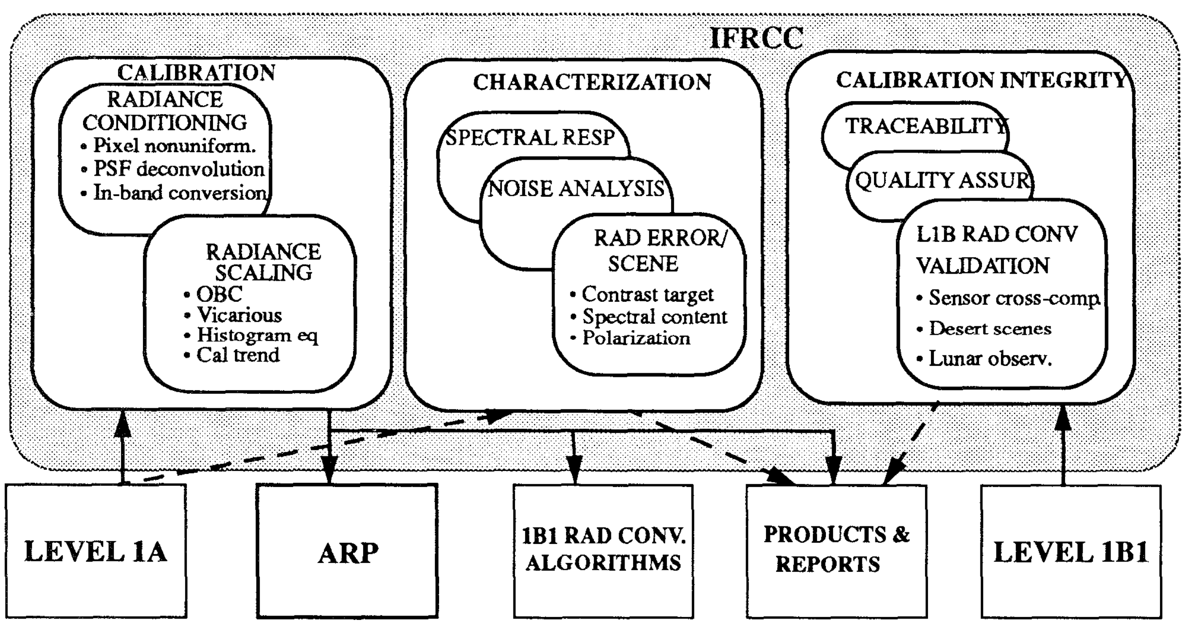

Fig. 1, IFRCC activities